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Options for System Upgrades of Rural Power Distribution Networks

India

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for

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Prepared by

Nexant SARI / Energy

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Disclaimer

List of Acronyms

ACSR	Aluminum covered steel reinforced (rabbit/weasel/squirrel – code names)
AEH	All Electric Homes
BESCOM	Bangalore Electricity Distribution Company
DISCO	Distribution Company
DT	Distribution Transformer
DTC	Distribution Transformer Center
FY	Fiscal year
GOS	Group operating switches
GP	Gram Panchayats
HT	High tension
HV	High voltage
HVDS	High voltage distribution system
IP	Irrigation Pump
KERC	Karnataka Electricity Regulatory Commission
km	kilometers
kv	kilovolt
kVA	kilovolt ampere
kvar	kilovolt ampere reactive
KW	kilowatt
KWh	kilowatt-hour
LLF	Loss Load Factor
LT	Low tension
mu	million units (million kWh)
MUSS	Master Unit Sub Station
mva	Mega volt-ampere
PRESK	participatory rural electricity services in Karnataka
pu	Per unit
RCC	Reinforced Cement Concrete

REC	Rural Electricity Corporation of India
Rs.	Indian Rupees (INR)
Rs. Crore	Rupees 10 million
SARI	South Asia Regional Initiative
SARI/E	South Asia Regional Initiative on Energy
Sf6	sulphur hexafluoride gas
Sl. No.	Serial Number
USA	United States of America
USAID	United States Agency for International Development
v	volt

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Executive Summary

The Need for Technical Support Groups at the District Level

India's rural power distribution networks are characterized by high losses, poor design and construction, inadequate maintenance, and large numbers of interruptions. Technical support groups, organized at the district level, could analyze the present network status, estimate losses in low-voltage and high-voltage networks, suggest improvements with the least investment per kWh of energy saved, and set priorities so that projects giving maximum returns are taken up first to make the best use of the limited available capital resources and having the least impact on consumer tariffs.

In each district there are 200-250 or more 11 kv feeders that need to be analyzed and improvement needs prioritized for each feeder. Digitized maps with all network data are needed to facilitate this analysis. Each district delivers about 1000 million kWh annually through poor quality high-voltage and low-voltage rural networks. A **20%** reduction in technical losses would mean reduction of nearly 200 mus of losses annually, which could have a substantial impact on the finances of the distribution companies. The analysis should be ongoing to provide the optimal network design with all expansions planned to reduce network losses.

District level technical support groups could also analyze interruptions and suggest measures to reduce them through the use of auto reclosures and other improvements. They could provide the technical and planning support to decentralized small distribution companies, including Gram Panchayats that decide to take over distribution functions. The area utility can take up responsibility for creating such district technical support groups or a private consulting group with appropriate experience could provide such service at a cost. The district technical group could also provide services, based on data available, such as preparing estimates for improvements and studies of support needed by area industries.

Adoption of HVDS

To achieve low losses, prevent theft by direct hooking, and reduce failure of distribution transformers due to unauthorized loads and clashing of conductors, high voltage distribution systems (HVDS) with small-size low loss transformers need to be adopted. The technical support group can study the optimal sites for adopting HVDS taking into consideration transmission line lengths.

Cost Reduction Measures

Efforts to reduce the capital investment while planning loss reduction measures are needed. For example, single-pole transformer mounting and special steel bolts to fix steel structures to reinforced cement concrete (RCC) poles could be utilized.

Use of New Materials for Robust Line Construction and for Improving Reliability

Use of aerial bunched cables, rigid spacers, bolt1ess wedge-type connectors, etc., are necessary to have robust 11 kv lines and to improve reliability of power in the rural networks. The importance of these new aids is highlighted in case studies illustrating the possible loss savings and advantages of wedge-type connectors over wrapped joints as well as the use of auto reclosures to enhance reliability. Relevant drawings are provided in the appendices to this report. The scope for the importing some of these new technologies is also considered.

Conclusions

District technical support groups providing loss assessment, prioritization of projects, advice on the use of new materials, and turn-key execution would assist in achieving the goal of optimal and reliable distribution networks. Together with other revenue enhancement measures, these upgrades would address many of the major problems of the power sector. Energy loss reduction in rural networks of 200 million kWh per year in each district will ultimately reduce the use of coal in thermal power plants by 60,000 tons annually, and distribution companies taking up aggressive loss reduction will be eligible for the equivalent carbon credits.

As part of USAID's South Asia Regional Initiative on Energy (SARI/Energy), which aims to foster energy sector co-operation in the region, a program for Participatory Rural Electricity Services in Karnataka (PRESK) has been funded. Nexant, Inc is providing technical assistance for this effort.

The activities undertaken by Nexant under this program include a study of the power distribution network, which is the last but the most important element in the energy delivery system. This report, based on the Nexant study, focuses on three areas:

1. The present condition of the distribution system;
2. The upgrades needed to deliver good quality power, particularly in rural networks, with the least technical and nontechnical losses; and
3. The introduction of new technology needed for to enhance electric power distribution reliability.

The study also examines whether new components and equipment are readily available, whether there is any need to import some of these, and possible changes in construction practices to create a more economical and robust network that will provide a more reliable and higher quality power supply in rural areas.

Any solution to the problems of the Indian power sector must include improving power distribution, especially in rural networks. The lack of careful planning of these networks has resulted in 40-50 km long 11 kv primary lines, undersized conductors, haphazard extensions, poor quality components, shoddy construction, and irregular maintenance practices, which have in turn produced poor voltage profiles, high levels of interruption, and high technical losses. A committee appointed by the Indian Government Ministry of Power to review the distribution systems and suggest measures for their improvement, including privatization, known as the "Distribution Committee" headed by Mr. Ashok Basu, has highlighted some of these issues. A relevant portion of the report is extracted here:

> *Distribution business in India has suffered from a number of problems, which have accumulated in the past fifty years. These problems primarily include lack of commercial orientation, excessive T and D losses, distorted tariff policies etc. The distribution operations in its present state, if allowed to continue, are likely to deteriorate further. Recognizing the current state of the sector, a number of committees have been formed and several important suggestions have been made for improvements (section 3.2.14). However, implementation of the suggestions has been uneven across the country and significant progress towards attainment of efficiency gains is yet to be made. Although there have been practical and real life limitations in the implementation of the recommendations, the most significant factor affecting implementation has been the lack of political will. There is an urgent need to evolve a consensus among all states towards reforms in power sector, which backed by resolute political commitment and action can transform the sector from its current state.* [1]
>
> *(i) Transmission and Distribution (T and D) losses*
>
> *The technical and commercial losses in 2000-01 were officially reported to be about **25%**. The reported figures of distribution losses underestimated the real extent of energy lost (or unaccounted for) because a substantial part of the losses were being shown as unmetered agricultural consumption. Based on the experience in some states, the actual levels of losses are much higher at about **40** to **50%** including about **15%** to **20%** of technical list losses along with **25%** to **30%** of commercial losses.*
>
> *Commercial losses are a euphemism for theft. Ministry of Power has for the first time recognized the magnitude of the problem and has indicated that theft of electricity is estimated to cost the country Rs. 20,000 crores per year. The technical losses are mainly due to over extended and overloaded low voltage distribution lines and weak distribution network. The commercial losses or theft are due to "illegal tapping" of low voltage lines, faulty metering and under billing.*

The need to bring in good planning concepts for distribution network development, technical loss assessment, prioritizing investment, new technology introduction, and improved construction practices for rural networks has to be given due importance as these improvements will also expedite the pace of sector reform. The technical problems indigenous to Indian rural distribution networks have to be tackled and effective solutions must be found.

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[1] *"Distribution Policy Committee Report"* – March 2002 – Ministry of Power, Committee headed by Mr. A.K Basu, Secretary, Power

This report presents the various issues relating to rural power networks. The on-the-ground realities are described, a distribution network planning arrangement that maintains decentralized distribution system management concepts for rural areas is proposed, and some technology improvements to ensure higher reliability in the rural power supply are suggested.

One of the reasons for the dissatisfaction of rural consumers – leading to the nonpayment of bills – is the quality and reliability of their power supply. Losses due to nonpayment in rural networks are currently very high, and reducing them will enable a reduction in overall expenditure. Around **75%** of the expenditure of distribution companies (DISCOs) is for power purchase cost, and input power can be reduced if aggressive loss reductions are realized.

This report has three focus areas:

1. Strengthening the network planning effort so that a continuous attempt is made to have an optimal network and to take up improvement schemes that have high benefit-to-cost ratios;
2. Improving construction practices in the distribution sector to ensure economy and reliability; and
3. Examining new equipment and technology that can be used in rural networks to enhance reliability and ensure better collections from rural consumer.

It is not that these measures are not already known, but this options report attempts to put them in proper perspective. Acceptance of changes in construction practices and strict adherence to planning concepts are difficult in a sector that firmly believes in traditional approaches and does not recognize the need for changes, particularly at lower levels of management.

4.1 District-Level Technical Support/Resource Groups

Because expansion of rural distribution networks is a highly dispersed activity that is spread over vast areas, expansion to meet new demand is usually decided by local engineers, who make decisions based more on the materials readily available than on considerations of optimal loss levels and high reliability.

Haphazard expansion, large low-tension to high-tension line ratios, excessive losses, and poor reliability can be directly traced to this reality, apart from the lack of adequate capital. There are many instances of well-planned networks soon turning into poor ones because of such materials considerations. To have an optimal network expansion plan, a separate agency to study and propose improvements would be necessary.

It is also necessary to have digitized maps of the areas with all electrical networks and their attributes marked on them for planning network expansion and improvements, after load flow studies have been conducted. These digitized maps would also help to create an asset record and history useful for various management purposes. The load flow programs used should consider the nature of the load in the network and dependence on terminal voltage. The energy loss estimation should consider the actual hours of supply to the rural areas and not standard loss load factors. Studies have indicated that adoption of standard load and loss load factors to convert peak power losses into energy losses are not reliable, as the supply practices are different for rural areas, with three-phase supply being highly regulated.

The Distribution Committee report has recommended that each district be treated as a distribution profit center. Keeping this in view, a "distribution network improvement support group" can be located in the headquarters for each district, which typically has about 10,000 km of 11 kv lines, 8,000 distribution transformers, and 20,000 km of low-tension lines, all totaling to around Rs. 2,000 to 2,500 million of assets. A digitized database of the network can also be maintained, which can be provided to local utility and other distribution management groups for a service charge.

There is also a strong case for breaking up the distribution business – particularly in rural areas – with local government agencies like Gram Panchayats (GPs) or franchisees managing the small local power distribution networks. This separation would lead to more efficient operations, improved revenue collection, and possibly increased local power generation through biomass and other alternative energy means.

As a district typically has 200-250 GPs, it would be inadvisable to have separate electricity planning facilities for each GP. A well-trained group from the utility or a private facility provider can provide these services to the local power distribution agencies. This technical support group can help in developing network improvements and planning capital works for the local power companies. The technical support group can examine least-cost expansion plans, considering the fact that sales in rural areas are more to subsidized sectors and, therefore, technical loss reduction in delivery systems will help the entire power sector.

Strengthening the planning process can cure one of the ills of the distribution sector — haphazard growth — and it can also work in the small network scenario managed by GPs.

Studies to be done by the technical support group can include:

- Changing conductors wherever small-size conductors are used and estimating the benefits and payback periods;
- Proposing new feeders from new and proposed substations for reconfiguring the network;
- Proposing reactive compensation after field measurements of existing load power factors;
- Proposals for high-voltage distribution system for feeders, taking into consideration the length of low- and high-tension lines; and
- Indicating overloaded feeders and proposing changes of conductors.

Distribution companies may typically have around 1,000 rural feeders and some studies indicate that Rs. 15-20 million must be invested to reduce technical losses in both low- and high- tension networks, from **30%** to **8-10%**, which means Rs. 1,500 crores will have to be invested if all feeders have to be tackled for loss reduction. The debt servicing cost of such investment will be Rs. 220 crores, assuming a borrowing rate of **10%** and debt repayment over 15 years. Table 4.1 provides an example of a utility and its estimated sales in rural areas for domestic, commercial, irrigation, and village water/street lighting.

Table 4.1: Typical Breakdown of Estimated Sales in Rural Areas

Category	Total Sales Estimates for FY03 (re) (mu)	Sales in Rural Areas (%, Assumed)	Estimated Sales in Rural Feeders (mu)
Bhagyajyothi/Kutirjyothi	114	90	102.6
Domestic	2,075	10	207.5
Commercial	408	5	20.4
Irrigation	3,279	90	2,951.1
Rural water supply/street light	173+198=371	70	259.7
Rural industries	821	5	41.5
Total			3,582 .8

Source: tariff order of the Karnataka Electricity Regulatory Commission (KERC) pertaining to the Bangalore Electricity Distribution Company (BESCOM); mu = million kWh

Taking the savings after system improvement as **20%**, the total savings will be 716 mu. At a bulk supply rate of Rs. 2.12, the annual savings will be 716 * 2.12 = Rs. 151.9 crores, which does not cover even the estimated annual debt servicing cost of Rs. 220 crores. The distribution reform review and assessment report prepared on behalf of USAID New Delhi states that the investment per unit of energy savings in rural projects varies from Rs. 7.3 to Rs. 37.8 per kWh per year, with payback periods varying from 3.1 to 24.8 years.[2]

This example clearly indicates that the improvements have to be prioritized, and those giving very high returns with less investment, such as replacing conductors and releasing overload on the 11 kv line, should be identified and taken up first. District-level technical groups would be needed to identify such priority projects and to provide the necessary databases, including digitized maps, since the increased workload of regular utility engineers would not allow sufficient time and attention for this important activity. It would also be desirable to plan how the identified work is to be executed. One approach would be a turnkey contractor with approved unit rates and an annual budget for the entire district taking on the work identified by the technical support group.

4.2 Adoption of A High-Voltage Distribution System

It is well known that the primary distribution lines (11 kV) in rural India's power network are long, sometimes over 50 km. If spur lines are taken into consideration, technical losses are as high as **15-20%**. The loss levels in four distribution companies in South India provided in the tariff order issued by the state regulator are detailed in Table 4.2.

Table 4.2: Utility Distribution Loss Details

Utility Details	Energy Input (mu)	Total Losses (<11 kV, %)	Estimated Energy Lost (mu)	Value (million Rs. @ Rs. 2.12/unit)
Utility A	12,823	21.35	2,738	5,804 .56
Utility B	5,635	21.28	1,199	2,541 .88
Utility C	5,683	27.71	1,574	3,336 .88
Utility D	3,858	27.05	1,117	2,368 .04

Source: Karnataka Tariff report. Bulk supply tariff of Rs. 2.12/kWh; mu = million kWh

The table shows that every percentage reduction in losses in utility A means a reduction of power purchase cost by Rs. 271 million, whereas in utility D it is Rs. 81.7 million. The benefit would be nearly double if the energy saved from losses is diverted and sold to paying commercial and industrial consumers. Further, because of inadequate capital availability and poor planning, more power is being pushed through small-size conductors, thus causing heavy overloads and high losses, as losses are proportional to the square of the current and length of line. And beyond the thermal limits of the conductor, the resistance increases, which has a further cascading effect on peak power losses.

The utility could identify and list the overloaded primary lines and make improvements to them a priority, diverting all available capital resources, as quick results would be possible. Also, analysis has shown that one of the major reasons for conductor-snapping leading to frequent power interruptions is the overloading of lines: Reliability can be substantially

[2] *"India Electricity Distribution Reform Review and Assessment"*, CORE International, for USAID, September 2002.

improved if overload on primary lines is released. Use of a high-voltage distribution system (HVDS) will reduce the loss levels more aggressively.

4.3 Network Efficiency and Adoption of HVDS

One measure of distribution network efficiency is the ratio of the length of low-tension lines (415 volts) to that of high-tension lines (11 kV), as losses in low tension lines are $((11000/415)^2)$ over 650 times that in high-voltage ones. This ratio is optimally around 1.0 or even less; it is usually in the range of 2.5 to 3.5 in rural networks.

Table 4.3: Typical Low- to High-Tension Line Ratios

Utility Name	Length of HT Line (km)	Length of LT Line (km)	Ratio of LT to HT Line
Utility A	50,479	140,122	2.78
Utility B	25,130	76,380	3.03
Utility C	38,443	88,630	2.30
Utility D	27,214	64,458	2.37

Source: KERC data

Table 4.3 clearly shows the need to transmit power at as a high voltage as possible to the ultimate user to reduce losses. The difference in the construction cost of high-tension, three-phase line and low-tension line with the same conductor is around **10%**. Therefore, installing small-size distribution transformers (DTs) of 10/15 kVA to meet the small loads instead of arranging supply from large-size DTs, say 63/100/250 kVA, is justified. As the load density in rural areas is low, it would be technically incorrect to have large-size DTs and long low-tension lines. Some analyses show that as much as a **20%** loss reduction is possible if HVDS are adopted. A study conducted in Karnataka for one of the rural feeders (Appendix A) indicates that the loss level will come down from **28.13%** to **17.66%** if HVDS is adopted and will further reduce to **9.9%** if both HVDS and high-tension network improvement are made. The investment estimated per kWh of energy saved per year is Rs. 2.59. The scheme is particularly attractive because high-tension line improvement is also being planned.

The loss level in 11 kv and below systems can be kept to less than **10%** if HVDS and high-tension network improvements are made and more efficient small-size transformers are selected. Further, HVDS will reduce low-tension lines thereby preventing unauthorized hookups and thus reducing commercial losses, which are estimated to be around **5%** to **7%**. (The Basu Distribution Committee report listed unauthorized hookups as contributing to high losses.)

4.3.1 Material Requirements

It is also necessary to analyze why this technically good solution has not been widely adopted. Apart from the additional capital needed for extension of 11 kv lines and providing small-size transformers (the payback period is less than a year in many instances), the major reason for not adopting HVDS is that 18-20 varieties of materials are needed for the extension of high-tension lines and installation of small-size transformers, while only seven or eight materials are needed for low-tension line extension. Field staff prefers to extend the network in a sub-optimal way rather than waiting for collection of all the required materials necessary for optimal expansion.

Design and construction practices will have to be reviewed critically to reduce the varieties of material required to simplify and speed up construction and reduce overall cost. The technical groups recommended in the preceding section can work out feeder-by-feeder the loss savings by adopting HVDS and establishing priorities that ensure quick returns.

The adoption of HVDS for an area or entire district, though desirable, would put a severe strain on finances because of debt-servicing and related costs, ultimately pushing up tariffs. As loss estimation takes only a fraction of the actual implementation cost, prioritizing investment would be in the interest of the entire sector.

Use of amorphous-core transformers, which give low no-load losses, would also be necessary as the number of small-size transformers would be four to five times that of conventional 63/100 kva transformers.

It should be recognized that adopting HVDS would increase the 11 kv line length substantially, thus increasing the possibility of fault incidence (by tree fouling, wind, etc.) leading to frequent interruption to all consumers. This issue, which must be addressed by introducing auto reclosures and sectionalizers along the 11 kv lines, is examined in detail in Section 4.7.

4.4 Single-Pole Transformer Mounting Arrangement

Use of HVDS means the number of transformers on a 11 kv feeder, generally between 40-60 (ranging in size from 63-100 kVA), will increase by four- to five-fold if small-size (15-10 kVA) transformers are installed, thus increasing the cost. It is, therefore, necessary to examine how the installed cost can be reduced. One possible economy is reducing the cost of pole-mounted transformers.

The typical pole-mounted transformer in rural networks in India is installed on two-pole structures, with eight or nine meter reinforced cement concrete poles. The cost of erection of 25 kVA, 63 kVA, and 100 kVA transformers is given in Table 4.4 below.

Table 4.4: Transformers and Accessories Cost Comparison

Size of Transformer	Cost Including Transformer (with RCC poles & LT kits, Rs.)	Cost of Transformer Alone (Rs.)
25 kVA	47,618.00	23,320.00
63 kVA	62,388.00	36,450.00
100 kVA	78,984.00	44,785.00

It can be inferred from the table that the per kVA cost (of accessories and installation, leaving out transformer costs) goes up from Rs. 342 for 100 kVA to Rs. 412 for 63 kVA and Rs. 954 for 25 kVA. This means if the conventional two-pole structure with more structural steel is used, the cost per kVA will go up further when smaller size transformers are adopted. And so methods for mounting the transformer on a single pole with reduced structural steel requirements must be developed to reduce the per kVA cost for accessories and labor, thus reducing the overall cost for erecting smaller sized transformers.

4.4.1 Pole Design

Poles are generally designed with rectangular cross sections to take care of the transverse wind load, and some poles are unsuitable in the single-pole formation for transformer installation. A square section pole is to be developed to take care of all loads including vertical loads, and poles of adequate height are to be adopted to achieve adequate clearances. A small-size transformer can be hung directly from the pole by drilling holes on site in the RCC pole using special machines and steel bolts. This attachment method can be used for other pole accessories, such as steel cross-arm and fuse units, thus reducing cost and improving overall aesthetics. Appendix B gives details of the arrangement for single-pole-mounted transformer centers.

4.4.2 Cost Reduction

The cost reduction due to the use of single poles and the associated reduction in steel clamps, bolts, and nuts, and labor would total about **30%** compared to the conventional two-pole arrangement. Where wood poles are used for power distribution, for example in the US, the transformers are fixed directly to the pole. The same arrangement is planned for RCC poles, by drilling holes on site using special tools and bolts. Experience has shown that a new transformer can be erected in three to four hours using a small crane. Even using the conventional method of chain-pulley-block the work can be completed, if all materials are available, in a day. Thus the speed of converting the system to HVDS can be enhanced to achieve the ultimate objective of loss reduction.

4.5 Use of Aerial Bunched Cables

For cost considerations, the overhead distribution system of bare conductors running on RCC poles and supported by porcelain insulators is used widely in Indian rural power networks. Although this system is adequate in open areas, it is unsuitable in areas having tree cover, particularly coconut and similar plantations. The short circuits caused by the clashing of conductors in the low-voltage network not only causes frequent interruptions but ultimately leads to failure of the distribution transformer, which is one of the biggest problems in the rural network. Transformer failure rates in typical utilities are given in Table 4.5 below.

Table 4.5: Transformer Failure Rates in Typical Utilities

Utility Name	Transformers in Service[1]	Transformer Failures / Failure Rate (%)	Monetary Loss for the Year (Rupees / year)[2]
Utility A	64,468	2,336 / 11.32	70.08
Utility B	36,989	4,842 / 13.09	145.26
Utility C	46,664	5,768 / 12.71	173.04
Utility D	25,939	3,962 / 15.27	118.86

1 Data for eight months only; prorated for 12 months while working annual monetary loss

2 Assuming repair and replacement costs of Rs. 20, 000/transformer

It should be noted that Utilities B and C have substantial parts of their distribution networks in wooded areas: Adoption of aerial bunched cables would probably reduce the failure of transformers thus reducing replacement expenditure and avoiding consumer complaints. One of the greatest causes of rural consumer dissatisfaction is the failure of distribution transformers and the failure to replace these in time to save standing crops. The reasons for failure are very likely overloading, unauthorized loads, poor quality repair and manufacture, poor maintenance and protection, and the clashing of conductors on the low-voltage side. The last reason is clearly indicated by the transformer failure rate going up in windy months, as illustrated in Table 4.6 for the Utility A example.

Table 4.6: Transformer Failure Rates by Month

	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Transformers Failed	950	1,280	1,020	900	700	800	785	690	670	690	620	750

Months given in boldface type are windy months; Data of utility A

An effective solution to the problem of conductor clashing that is cheaper than installing intermediate poles is to provide rigid PVC spacers as per Rural Electricity Corporation of India (REC). As a construction practice it is preferable to provide spacers in the three-phase, four-wire network, at least near the transformer centers. The better technology option would be insulated aerial bunched cables made per relevant standards by reputed manufacturers, although this is costlier than overhead conductors.

The use of rigid spacers becomes extremely attractive if HVDS with one or two spans of low-voltage line is considered. Use of ABC system low-voltage networks also prevents unauthorized hooking up as it very difficult to do this with cross-linked polyethylene insulation, thus taking care of one of the major reasons for theft and commercial losses. Feeder-by-feeder improvements to transformer centers, like improved protection and electrical connections, neutral grounding, removing overloads and unbalanced loads, and other maintenance work, would also reduce the failure rate of transformers.

4.6 Use of Good Quality Conductor Accessories

A report prepared by an international lending agency[3] has pointed out that losses in conductor joints are as high as **4%** in Indian utilities. This can be substantially reduced if good-quality connectors are used in the power distribution network, starting from the primary substations where DISCOs receive power at 11 kv right up to the ultimate consumers. The power has to move over the 11 kv line, then through the transformer to the low-voltage network and from there on to the consumer through the service mains.

Since most networks are radial, it is essential to have robust, long-life, low maintenance systems to provide a reliable and economical power supply – especially as fault repair costs are high, particularly in rural areas.

In present practice, bolted or compression-type connectors are used in the 11 kv lines. Quite often spur line and transformer taps are teed off using wrapped joints, in which the aluminum

[3] *"Staff Appraisal Report"*, World Bank Mission visit to BESCOM, 2002.

wire is wrapped one over the other to take off the connection. This is widely adopted in the low-voltage distribution system, including the tapping to the consumer service wire.

Wrapped joints worked well when copper was being used in the construction and experienced linesman did the work. But with aluminum replacing copper and inexperienced staff replacing experienced linesmen, the quality declined, leading to frequent interruptions and increased losses due to loose contacts.

Use of bolted connectors is also not desirable as the power flow throughout the day varies, causing temperature variations, which expand and contract the connections. Over time the connection becomes loose, leading to loose contact, increased resistance, and increased losses, ultimately leading to the failure of the connection and loss of power supply. A study done in one of the utilities of the benefit of boltless connectors made these findings:

- Wires were wrapped too near the low-voltage side of the power transformer, where current flow is maximum (hence losses are high), leading to poor connection and high resistance of 554.3 micro ohms. When this connection was replaced by a fired-wedge connector, the resistance came down to 70 micro ohms – a factor of eight, thus reducing losses by **88%** (Appendix C). The calculations show that the extra investment is paid for in two years, assuming energy cost at Rs. 2.50 per kWh. When increasing energy costs and loss of revenue from consumers is also considered, then the payback period will be much less, say less than one year.
- The following new types of connectors are available for use:
  - Wedge-type, internally fired connectors;
  - Universal distribution connectors; and
  - Wedge connectors for small-size conductors.

These connector types are described in detail in Appendix D (1, 2, and 3). Wherever heavy currents are flowing and short circuit currents are high, like in 11 kv lines, connectors such as those illustrated in D-1 and D-2 can be used. The costs are fully justified if loss reductions and savings in repair costs are considered. The small connectors illustrated in D-3 are ideal for tapping consumer connections from the street-side poles. Considering that house/consumer connections are millions in number, the use of good connectors will not only save losses but also improve reliability of supply both in urban and rural areas.

Similarly, the use of pre-formed insulator ties and dead end connections improves the quality of line construction and adds to the reliability of the power supply.

4.6.1 Availability

The problem in India is that such options are not locally available, but importing from well-reputed manufacturers is a good option. Aggressive marketing, highlighting the benefits of loss reductions and the higher reliability of power, has to be done, especially as power sector reforms lead to the introduction of new players, who are likely to be more interested in loss reduction and reliability.

4.7 Use of Auto Reclosures and Sectionalizers in Rural Networks

For economic reasons, electrical power for rural consumption is invariably supplied through overhead radial lines. Consequently, the system is exposed to frequent interruptions of supply because of lightning, adverse weather, birds, tree damage, animals, and wind blown foliage. The 11 kv networks are around 50 km in length (in some cases more), and if the high-voltage distribution systems considered here are widely adopted, the primary line length will *further* increase. In such a scenario, a fault occurring any where on the 11 kv line or on the primary side of the small-size transformer will isolate the entire line at the substation end causing power interruption to all the consumers served by the feeder, which may 1,500 to 2,000 consumers.

Further, with the initial sections of the 11 kv lines emanating from the substation feeding the town loads and rural loads beyond the town border, frequent power interruptions occur to revenue-yielding installations, such as rural industries and water supply installations. It is, therefore, necessary to localize the faults and make arrangements to provide power to as many consumers as possible.

Records indicate that many of the rural feeders have 30-40 interruptions per month, some reaching as high as 100 depending on the terrain the line traverses. For each interruption, it may take two to four hours to restore power, depending on the location of the fault, availability of repair crews, the nature of the fault, and so on. The repair cost is high, in the region of Rs. 800 to 1,000 per fault, assuming a two-member crew will take about eight hours (including travel time) to set right the fault with a man-day cost of Rs. 50 per hour.

The resulting loss of revenue can be substantial if there are major revenue-yielding installations on the line. The often heard complaint from rural consumers is that in the limited hours of supply given to them, the feeder line often trips, interfering with their field watering work; many times the interrupted supply does not allow the water to reach the far end of the land, so their farm labor is also wasted.

Auto reclosures and sectionalizers, which have been used widely in other countries, can localize the fault and allow the power supply to be restored to the healthy section, greatly improving the situation and increasing the reliability of supply and satisfaction of consumers.

The 11 kv line is generally protected by a circuit breaker at the substation end. This breaker has both fault power interruption and load making and breaking capability. The ratings are generally high to match the system requirements. This circuit breaker trips for all faults frequently and as a result the maintenance requirements will go up even if vacuum or sulphur hexafluoride gas (Sf6) breakers are used. A combination of auto reclosures and sectionalizers can be used along the line to remedy the situation.

4.7.1 Auto Reclosures

A reclosure is a six-bushing type breaker (either pole- or plinth-mounted) having a lower current rating, say 200 or 400 amperes (against the 630, 800, 1200 amps of station end breakers), with the capacity to break both load and fault current. Breakers can be either vacuum or Sf6 type. This will have devices to detect faults and trip the breaker before the station end breaker trips, thus protecting supply to the transformers and consumers upstream of the location of the reclosure. A typical auto reclosures is shown in the Appendix E**.**

The automatic reclosures also have provisions for four-shot reclosing features to address the problem of repetitive temporary faults, which get cleared after two or three reclosings when faults are burnt (such as tree branches close to the line) and line integrity is restored. All the while the duty on the station breaker, like tripping on fault (with its operating mechanism put to repetitive use), is avoided, reducing maintenance requirements.

4.7.2 Sectionalizers

The reliability of rural networks can be further improved if one or two sectionalizers are also added along the line after the location of the reclosure. These sectionalizers can be provided on the longspur lines or sections of line that pass through forest or heavy tree cover. Sectionalizers are mere load break switches with no ability to break fault current. If there is no incoming supply, the unit locks out. The unit can also be remotely operated like the reclosure, making it suitable for distribution automation at a later date.

In situations where there is an auto reclosure in combination with two sectionalizers, the fault is seen by the protective device in the reclosure, it trips and the sectionalizer also opens out due to loss of incoming supply and closes when supply is restored. On a second fault, however, the sectionalizer locks out, protecting supply to the healthier sections on the line. Thus many customers regain supply quickly and reliability improves.

4.7.3 Use of Auto Reclosures and Sectionalizers

Reclosures and sectionalizers would be recommended where:

1. High lightning activity is combined with exposed overhead lines;
2. Fuses protect downstream spur lines;
3. A spur line has a large concentration of customers;
4. Sites are remote; or
5. A portion of spur lines passes through wooded areas.

A study conducted by an Australian[4] supply utility found that an initial outlay of Aus$100,000 on reclosure protection would save around $120,000 annually and would add Aus$1,000,000 to shareholder value. This estimate is based on the existing practice of extensive use of fuses for rural feeders and information showing that **80%** of all faults are temporary, cleared by reclosure operation. They recommend remotely controlled reclosures, as distances are large in Australia. In the beginning, remote features need not be adopted to save on cost but units suitable for the same can be purchased so that retrofitting can be done at a later stage. A case study done for a utility in South India (Appendix F) indicates that Rs. 1.3 million is lost each year due to faults, whereas the first cost of a reclosure and a sectionalizer would be Rs. 0.35 million, thus justifying the investment.

[4] Auto Recloser Article: *Bharat Heavy Electrical Limited (BHEL), New Delhi, September 2003 (Referencing: Study of Rural Feeders by Great Southern Energy, Australia)*

Importation of Technology and Equipment

Although there are local companies capable of providing support for technical studies and for mapping, there will be ample opportunities for outside companies to provide assistance not only in system studies of distribution network but also in such areas as the study of harmonics, phase compensation for load balancing, and reactive compensation. Concerning equipment, there is good potential for importing special type boltless connectors for overhead lines and piercing type connectors for aerial bunched cables, as only one local company is now attempting to market these. Also, the potential for using auto reclosures and sectionalizers in rural feeders is high and only one public sector company is in the market at present. Aggressive marketing highlighting the advantages of these items and services with demonstration projects would be required to achieve results.

Section 5 Conclusions

A thorough study of the distribution network is needed for prioritizing the adoption of new cost-effective construction methodology and the use of modern tools, such as reclosures, that will reduce technical and nontechnical losses and improve the quality and reliability of rural energy supply, thus paving the way for better rural revenue collections. Improvement of the overall health of the power sector is possible if these and other measures, such as improved metering, billing, and better management practices, are put into practice.

1.1 Budhigere Feeder Details

The Budhigere feeder is fed from the Devanahally 66/11 kv master unit sub station (MUSS), which is about 10 km from Budhigere village. The installed capacity of power transformers at the Devanahally MUSS is 2x20 mva.

Table AppA-1 gives the distribution line parameter details for different conductor configurations. This feeder has Rabbit aluminum covered steel reinforced (ACSR) conductors *[copper equivalent area of 30 sq. mm]* for 11.45 km, Weasel ACSR conductors*[copper equivalent area of 20 sq. mm]* for 4.65 km, and Squirrel ACSR conductors*[copper equivalent area of 13 sq. mm]* for 5.4 km. It is a purely rural feeder, mainly to irrigation pump (IP) sets and village residential installations, including 11 villages: Baichapura, Anneswara, Honasur, BK palya, Singahaly, Arebannimangala, Manchapanahally, Gollahally, Kondenahally, Batramarenahally, and Kaggalahally. Categories of installations connected on this feeder are as follows:

Table App 1-1: Distribution Line Parameters

Sl No	Category of Installations	Numbers
1	LT-1A – BJ/KJ	116
2	LT-1B – Domestic lighting	652
3	LT-2 – AEH	4
4	LT-3 – Commercial lighting	2
5	LT-4 – IP sets	399
6	LT-5 – LT power	14

The load flow study considers a detailed representation of the feeder by taking into consideration the point-to-point distance of tap points and location and capacity of distribution transformers. The total length of the trunk line for the Budhigere feeder is 13.5 km. The total length of the spur lines is about 8.0 km.

Table AppA-2 gives the distribution transformer details for this feeder. The peak load recorded on this feeder was 230 A. Table AppA-3 gives monthly energy recorded on this feeder from June 2002 to February 2003. The hourly readings of current and voltage on November 3, 2002, the day on which peak load was recorded, is shown in Table AppA-4.

1.1.1 Observations

- The peak current recorded at the MUSS exceeds the peak current computed based on the connected load data obtained from the load survey.
- The IP set loadings are generally found to be higher than the sanctioned load.

- The recorded sending end current during the peak load condition is 230 A at 11.5 kV. The total kVA capacity at the sending end works out to be 4,581 kVA whereas the total distribution transformer capacity is 3,800 kVA.
- The field measurements were also made for the Budhigere feeder on April 10, 2003. It was found that some of the IP connected transformers are overloaded up to the extent of **150%**.
- Hence for the simulation studies, the IP set loads were uniformly increased to match the sending end current of 230 A.

Table App 1-2: Transformer Details

Sl No	Rating (kVA)	Number of Transformers	Total Capacity (kVA)
1	250	01	250
2	100	18	1,800
3	63	25	1,575
4	25	07	175
Total		51	3,800

Table App 1-3: Peak Load and Energy Recorded (June 2002 to February 2003)

Year	Month	Peak Load Current A	Energy Recorded (kWh)	Remarks
2002	June	250	788,800	Budhigere and Channahally branches are feeding together
2002	July	280	1,127,040	
2002	August	300	1,066,200	
2002	September	310	950,720	
2002	October	300	924,080	
2002	November	320	944,880	
2002	December	350	1,047,000	
2003	January	360	1,256,400	
2003	February	340	1,054,640	
2003	March	230		Separate feeding for Budhigere

Table App 1-4: Hourly Reading on 11th March 2003
(Day of Peak Demand of 230 A Recorded)

Sl No	Hour	Loading for Budhigere Branch (A)	Loading for Channahally Branch (A)	Voltage (kV)	Remarks
1	1	L/S	L/S	11.5	
2	2	L/S	L/S	11.5	
3	3	230	L/S	11.5	Budhigere branch given three-phase supply
4	4	230	L/S	11.5	
5	5	L/S	160	11.5	Channahally branch given three-phase supply
6	6	L/S	160	11.5	
7	7	L/S	L/S	11.5	
8	8	L/S	L/S	11.5	
9	9	L/S	L/S	11.5	
10	10	L/S	L/S	11.5	
11	11	L/S	180	11.5	Channahally branch given three-phase supply
12	12	L/S	180	11.5	
13	13	L/S	170	11.5	
14	14	L/S	L/S	11.5	
15	15	180	L/S	11.5	Budhigere branch given three-phase supply
16	16	180	L/S	11.5	
17	17	170	L/S	11.5	
18	18	L/S	L/S	11.5	
19	19	140	L/S	11.5	1,900-1,930 hrs load shedding for Channahally branch
20	20	L/S	150	11.5	Rostered supply
21	21	280	-	11.5	Rostered supply for the both the branches
22	22	290	-	11.5	
23	23	L/S	L/S	11.5	
24	24	L/S	L/S	11.5	

Note: L/S indicates load shedding

1.2 About the HVDS System

The Bangalore Electricity Distribution Company (BESCOM) system generally comprises 25, 63, 100, 200, 250, and 500 kVA distribution transformers located at load centers. The services to consumer premises are drawn from the distribution transformer centers (DTCs) with low tension (LT) lines of three-phase four-wire or five-wire and single-phase two-wire or three-wire systems. Due to low load densities in the rural areas, the LT network is generally more than 1 to 2 km and hence causes higher LT line losses and poor voltage regulation.

Due to energy and peak power shortages, it is necessary to control the loads; this is being carried out by way of load shedding (scheduled and unscheduled) and rostering the rural feeders. Rostering rural feeders disables the three-phase loads on the rostered feeder, thereby allowing only single-phase lighting and commercial loads to operate. To avoid the restrictions imposed on three-phase loads, farmers have resorted to energizing their irrigation pump sets even during roster hours by employing phase-shifting capacitors. This causes imbalances in the three-phase system and introduces negative and zero sequence currents. Use of capacitors to convert the single-phase supply to run the motors increases the losses in the distribution system and may also cause damage to the transformers.

By applying the high voltage distribution system (HVDS), the single-phase loads can be in service all the time and incidence of three-phase loads can be fully avoided. In HVDS, smaller capacity 10/15 kVA transformers will replace the conventional higher capacity transformers. All the single-phase loads will be segregated and connected to single-phase 10/15 kVA transformers. At the substation a special arrangement of group operating switches (GOS) capable of closing and opening individual phases will be installed. During the normal supply hours all the phases will be closed. During single phasing only one phase will be closed with the remaining two phases kept open. The single-phase transformers proposed are of 6.3 kV/250 V, 10/15 kVA rating and will be connected between phase conductor and earth.

1.3 Advantages of the HVDS System

The HVDS has the following advantages:

- Availability of single-phase supplies throughout the day for domestic and commercial consumers and associated social benefits;
- Better energy and peak load management;
- Reduced LT line losses due to smaller LT networks and better voltage regulation;
- Increased reliability of the distribution system;
- Reduced commercial losses and failure of distribution transformers;
- Individual transformers of smaller capacity, resulting in better maintenance and assisting in identifying un-authorized pump connections, if any, will supply IP sets.

1.4 Analysis and Results

1.4.1 Load Flow Analysis of the Budhigere Feeder for Existing Scenario

The load flow analysis for the peak power condition (230 A) was conducted for the Budhigere feeder for the existing scenario. Following results are derived from the load flow study:

- The load supplied at station end: 3,750/2,630 kW/kvar
- The minimum voltage observed: 8.9 kV

- Peak load current at the station: 230 A
- The total real power losses in the system: 1,340 kW
- Number of feeder sections loaded beyond the rated capacity: 9

Voltage profile at all the 11 kv buses during the peak load condition for the existing scenario is given in Table AppA-5, which shows the voltage ranges of 11 kv and 415 v busses during the corresponding peak load condition. The line flows and percentage loading of Budhigere feeder for the peak load current of 230 A for the existing scenario is also given.

Table App 1-5: Voltage Profile for 11 kv and 415 v Buses

Sl No	Description	No of Buses (11 kV)	No of Buses (415 V)
1	Bus voltages ranging between 100-110%	3	-
2	Bus voltages ranging between 90-100%	9	78
3	Bus voltages ranging between 80-90%	41	295
4	Bus voltages ranging between 70-80%	-	399
5	Bus voltages ranging between 60-70%	-	250
6	Bus voltages ranging between 50-60%	-	122
7	Bus voltages ranging less than 50%	-	36

From the results of the existing scenario it was observed that loading on the initial nine sections is more than **100%**. The voltage profiles of 41 11 kv buses are in the range of **80%** to **90%**. In the LT system, it was observed that there are about 408 buses that are below **70%** voltage and 36 buses are below **50%** voltage. Hence voltage regulation on the LT system is poor.

1.4.2 Load Flow Results for Existing Scenario

Table AppA-6 presents the summary for the existing scenario of load flow results and zone-wise losses for the Budhigere feeder for the peak load current of 230 A. Table App 1-6: Summary of Load Flow Results

Sl No	Description	HT Side	LT Side	Total
1	kw sending end	3,750	-	3,750
2	kvar sending end	2,630	-	2,630
3	kw load supplied	-	2,410	2,410
4	kvar load supplied	-	1,810	1,810
5	Total real power loss in kW	890	450	1,340
6	Total reactive power loss in kvar	720	100	820

Sl No	Description	HT Side	LT Side	Total
7	Percentage real power loss (peak)	23.7%	12.0%	35.7%

The load curve generated for a day when peak load was recorded, March 11, 2003, for the existing scenario is shown in Figure AppA-1.

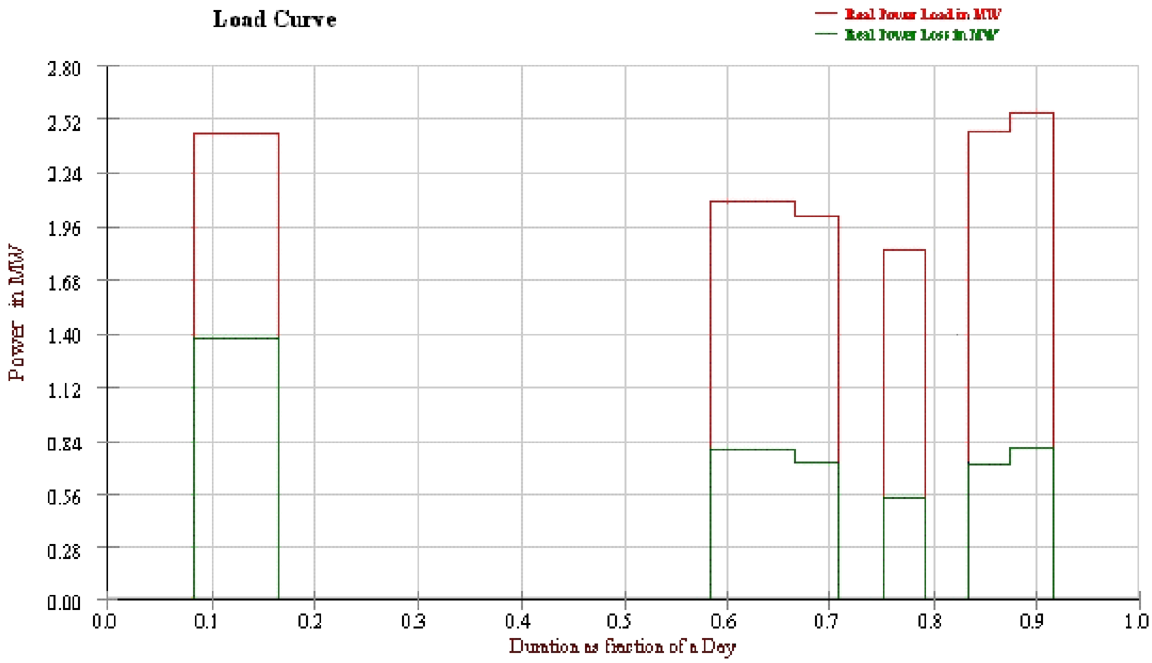


Figure App 1-1: Load Curve Recorded on 11.3.03

Table App 1-7: Power and Energy Loss Computation

Sl No	Description	Value
1	Maximum generation in kW	3,750
2	Average generation in kW	1,031
3	Load factor	0.275
4	Loss load factor	0.217
5	Energy sent out per month in kWh	746,820
6	Load energy per month in kWh	534,948
7	Monthly energy loss in the HT lines in kWh	139,225
8	Percentage HT line energy loss	18.64%
9	Monthly energy loss in the LT lines in kWh	70,864
10	Percentage LT lines energy loss	9.49%
11	Monthly total energy loss in kWh	210,089
12	Percentage of total energy loss	28.13%

1.4.2 Load Flow Analysis of the Budhigere Feeder for Modified Scenario

The load flow analysis for the peak power condition was conducted for Budhigere feeder for the modified scenario.

Two alternatives for connecting single-phase transformers have been analyzed. In alternative 1, it is assumed that all the single-phase transformers are connected between selected phase and earth. In alternative 2 , single-phase transformers are connected on R to earth, Y to earth, and B to earth. During single-phase operation all three phases are bunched at the sending end and only one selected phase is energized.

Alternative 1

For this alternative, it is assumed that all the single-phase transformers are connected between R-phase and earth.

The following results were derived from the three-phase load flow study:

- The load supplied at station end: 3,042/2,089 kW/kvar
- The minimum voltage observed (11 vide): 8.3 kv in R phase
- Peak load currents in three phases (RYB) at the station: 228/172/180 A
- The total real power losses in the system: 552 kW

The voltages of R-Y-B phases at all the 11 kv buses during the peak load condition for the modified scenario for Alternative 1 is given.

Table AppA-8 presents the voltage profile of 11 kv and 415 v busses during the peak load condition for alternative 1.

Table App 1-8 Voltage Profile for 11 kv and 415 v Buses – Alternative 1

Sl No	Description	No of Buses (11 kV)	No of Buses (415 V)
1	Bus voltages ranging between 90% - 100%	12	269
2	Bus voltages ranging between 80% - 90%	75	679
3	Bus voltages ranging between 70% - 80%	184	52
4	Bus voltages ranging between 60% - 70%	-	-
5	Bus voltages ranging between 50% - 60%	-	-
6	Bus voltages ranging less than 50%	-	-

From the results it is observed that, at 11 kV, bus minimum voltage is 0.75 pu in R-phase. There are 184 11 kv buses below **80%** voltage. Also heavy imbalance in voltage is seen when both three-phase and single-phase loads appear simultaneously. Simultaneous occurrence of three-phase and single-phase load is, however, very low, so the imbalance in voltages may not be a serious problem. In the LT voltage, it is observed that there are no buses below **70%** voltage, while in the existing scenario there are about 408 buses below the **70%** voltage limit.

The phase-wise line currents in amperes of all the 11 kv lines during the peak load condition for the modified scenario for alternative 1 are given. From the results it is observed that the R-phase, on the phase to which single-phase transformers connected gets over loaded compared to the other phases

Alternative 2

For this alternative, it is assumed that single-phase transformers are connected between R to earth, Y to earth, and B to earth. It is presumed that during three-phase operation the single-phase loads are judiciously distributed among the three phases for the entire feeder. During single-phase operation for example R phase energized and Y-B are kept open the R-Y-B conductors will be bunched together at the sending end. This mode of operation results in lower line losses and better voltage regulation.

Following results are derived from the three-phase load flow study:

- The load supplied at station end: 3,021 /2,071 kW/kvar
- The minimum voltage observed: 8.8 kV
- Peak load current on R-Y-B phases: 187/196/194 A
- The total real power losses in the system: 534 kW

The voltages of R-Y-B phases at all the 11 kv buses during the peak load condition for the modified scenario with Alternative 2 is given.

Table App 1-9 Voltage Profile for 11 kv and 415 v Buses – Alternative 2

Sl No	Description	No of Buses (11 kV)	No of Buses (415 V)
1	Bus voltages ranging between 90-100%	57	269
2	Bus voltages ranging between 80-90%	213	679
3	Bus voltages ranging between 70 -80%	-	52
4	Bus voltages ranging between 60 -70%	-	-
5	Bus voltages ranging between 50 -60%	-	-
6	Bus voltages ranging less than 50%	-	-

From the results, it is observed that at 11 kV, bus minimum voltage is 0.8 pu in R-phase. All the 11 buses are above **80%** voltage. The imbalance seen in the voltage is much less when both three-phase and single-phase loads appear simultaneously. It is also observed that the voltage profile is more or less equal in all three phases. In the LT voltage, it is observed that there are no buses below **70%** voltage, while in the existing scenario there are about 408 buses below the **70%** voltage limit.

The phase-wise line flows in amperes of all the 11 kv buses during the peak load condition for the modified scenario with alternative 2 is given. From the results it is observed that the peak power loss in the 11 kv system declines from 518 kw (Alternative 1) to 500 kw (Alternative 2). Also, the currents are more or less equal in all three conductors, thereby avoiding the overloading of any one conductor.

The voltages of R phases at all the 11 kv buses during the single-phase loading condition for the modified scenario are given. From the results, it is observed that the voltage regulation is very good, as the percentage of single-phase load is very small compared to three-phase load (approximately **10%** of the total load).

1.4.3 Load Flow Results for Modified Scenario

Table AppA-10 and Table AppA-11 present the summary for the modified scenario of load flow analysis results and zone-wise losses for the Budhigere feeder for the peak load condition.

Table App 1-10: Summary of Load Flow Analysis

Sl No	Description	Alternative 1	Alternative 2
1	kw Sending end	3,042	3,021
2	kvar Sending end	2,089	2,071
3	kw load supplied	2,521	2,521
4	kvar load supplied	1,783	1,783
5	Total real power loss in kW	552	534
6	Percentage peak power loss	18.15%	17.67%

Table App 1-11: Zone-wise Losses

		Alternative 1		Alternative 2	
Sl No	Description	HT Side	LT Side	HT Side	LT Side
1	kw Sending end	3,042	3,042	3,021	3,021
2	kvar Sending end	2,089	2,089	2,071	2,071
3	kw load supplied	2,521	2,521	2,521	2,521
4	kvar load supplied	1,783	1,783	1,783	1,783
5	Real power loss in kW	518	34	500	34
6	Percentage real power loss	17.03%	1.12%	16.55%	1.12%

The energy loss computations are tabulated in Table AppA-12.

Table App 1-12: Power and Energy Loss Computation – Alternative 1

Sl No	Description	Value
1	Maximum generation (kW)	3,068
2	Average generation (kW)	1,322
3	Load factor	0.431
4	Loss load factor	0.417
5	Energy sent out per month (kWh)	940,145
6	Load energy per month (kWh)	774,153
7	Monthly energy loss in the HT lines (kWh)	155,768
8	Percentage energy HT lines energy loss	16.57%
9	Monthly energy loss in the LT lines (kWh)	10,224
10	Percentage energy LT lines energy loss	1.09%
11	Monthly total energy loss (kWh)	165,993
12	Percentage total energy loss	17.66%

Table App 1- 13: Summary of Results

Sl No	Description	Existing Scenario	HVDS without HT Line Improvements	HVDS with HT Line Improvements
1	kw sending end	3,750	3,042	2,807
2	kvar sending end	2,630	2,089	2,071
3	kw load supplied	2,410	2,521	2,521
4	kvar load supplied	1,810	1,783	1,783
5	Total real power loss in kW	1,340	552	286
6	Percentage peak power loss	35.7%	18.15%	10.18%
7	Energy sent out per month	746,820	940,145	859,555
8	Load energy per month	534,948	774,153	774,153
9	Monthly energy losses	210,089	165,993	85,401
10	Percentage of monthly energy loss	28.13%	17.66%	9.9%

Table AppA-14 and Table AppA-15 present the transformer no load and full load losses for the existing and modified scenario of the Budhigere feeder.

Table App 1-14 Transformer No Load and Copper Loss – Existing Scenario

Sl No	kVA Capacity	Numbers	Iron Loss (W)	No Load Loss (Units)	Cu Loss (W)	Total Copper Loss (Units)
1	25	9	100	3,240	685	4,816
2	63	23	180	14,904	1,235	22,190
3	100	18	260	16,848	1,760	24,748
4	250	1	620	2,232	3,700	2,890
Total	51		37,224		54,644	
Total transformer losses 91,868 units per year						

Assuming transformers are working for 10 hours only

Table App – 1-15 Transformer No Load and Copper Loss – Modified Scenario

Sl No	kVA Capacity	Numbers	Iron Loss (W)	No Load Loss (Units)	Cu Loss (W)	Total Copper Loss (Units)
1	15 S-phase	30	45	11,826	275	30,136
2	15 three-phase	196	80	56,448	475	139,762
Total	226		68,274		169,898	
Total transformer losses 238,172 units per year						

Assuming single-phase transformers are working for 24 hours and the three-phase transformers are working for 10 hours

1.4.4 Feasibility Studies

The following four improvement schemes were proposed for the Budhigere 11 kv feeder to reduce the losses.

1.4.4.1 Case 1

For the existing scenario, reconductoring all the existing 11 kv lines (Weasel and Squirrel) for a distance of 10 km by Rabbit and providing additional circuit for a distance of 4.65 km from MUSS. The feasibility analysis carried out for the above case is as follows. For all the feasibility studies existing energy sent out, load factor (0.275) and loss load factor (LLF) (0.217) is used.

Table AppA-16: Feasibility – Case 1

Sl No	Description	Base Case	Case 1
1	Peak load (A)	230.00	215.3
2	Sending end power at peak load (MW)	3.75	3.49
3	Total load at peak load (MW)	2.41	2.49
4	Peak power loss (MW)	1.34	1. 0
5	Proposal made		Additional circuit
6	Proposal km		4.65
7	Cost per unit length (Rs)		107,760
8	Proposal made		Reconduc-toring
9	Proposal km		10
10	Cost per unit length (Rs)		60,081
11	Investment in the proposal (Rs)		1,101,894
12	Interest charges (%)		10.0
13	O and M charges (%)		3.0
14	Life of the project (years)		20.0
15	Energy charges per unit (Rs)		2.30
16	Annual expenses (Rs)		143,246
17	Energy savings (units/year)		601,485
18	Annual income on energy saving (Rs)		1,383,416
19	Annual benefit		1,240,169.5
20	Annuity factor		8.5
21	Present worth of annual benefit		10,558,262.5
22	Net present worth		9,456,368.5
23	Benefit to investment ratio		9.58
24	Feasibility of project		Feasible
25	Payback period (years)		2.2

1.4.4.2 Case 2

For the existing scenario, it is proposed to provide additional circuit for a distance of 4.65 km from MUSS and reconductoring of the overloaded 11 kv and LT lines by Rabbit conductor for a distance of 20 km. The feasibility analysis carried out for the above case is as follows.

Table App 1- 17: Feasibility – Case 2

Sl No	Description	Base Case	Case 2
1	Peak load (A)	230.00	202.50
2	Sending end power at peak load (MW)	3.75	3.22
3	Total load at peak load (MW)	2.41	2.53
4	Peak power loss (MW)	1.34	0.69
5	Proposal made		Additional circuit
6	Proposal km		4.65
7	Cost per unit length (Rs)		107,760.00
8	Proposal made		Reconductoring
9	Proposal km		20
10	Cost per unit length (Rs)		60,081
11	Investment in the proposal (Rs)		1,702,704
12	Interest charges (%)		10
13	O and M charges (%)		3
14	Life of the project (years)		20
15	Energy charges per unit (Rs)		2.3
16	Annual expenses (Rs)		221,351.5
17	Energy savings (units/year)		1,194,572.2
18	Annual income on energy saving (Rs)		2,747,515.9
19	Annual benefit		2,526,164.5
20	Annuity factor		8.5
21	Present worth of annual benefit		21,506,662
22	Net present worth		19,803,958
23	Benefit to investment ratio		12.6
24	Feasibility of project		Feasible
25	Payback period (years)		1.6

1.4.4.3 Case 3

For the modified scenario (HVDS), the feasibility analysis carried out for the above case (1.2) is as follows.

Table AppA-18: Feasibility – Case 3

Sl No	Description	Base Case	Case 3
1	Peak load (A)	230.00	194.
2	Sending end power at peak load (MW)	3.75	3.07
3	Total load at peak load (MW)	2.41	2.52
4	Peak power loss (MW)	1.34	0.55
5	Proposal made		HVDS with 30 single-phase and 196 three-phase transformers
6	Cost per unit length (Rs)		996,8820
7	Proposal made		Improvements
8	Proposal km		-
9	Cost per unit length (Rs)		-
10	Investment in the proposal (Rs)		9,968,820*
11	Interest charges (%)		10.0
12	O and M charges (%)		3.0
13	Life of the project (years)		20.0
14	Energy charges per unit (Rs)		2.30
15	Annual expenses (Rs)		1,295,946.6
16	Energy savings (units/year)		1,263,554.8
17	Annual income on energy saving (Rs)		2,906,176.0
18	Annual benefit		1,610,229.4
19	Annuity factor		8.5
20	Present worth of annual benefit		13,708,790.9
21	Net present worth		3,739,970.9
22	Benefit to investment ratio		1.38
23	Feasibility of project		Feasible
24	Payback period (years)		14.5

1.4.4.4 Case 4

For the modified scenario (HVDS) it is also proposed to provide additional circuit for a distance of 10 km from MUSS and reconductoring the existing 4 ACSR by 2 ACSR conductor. The feasibility analysis carried out for this case is as follows.

Table App 1-19: Feasibility – Case 4

Sl No	Description	Base Case	Case 4
1	Peak load (A)	230.0	177
2	Sending end power at peak load (MW)	3.75	2.85
3	Total load at peak load (MW)	2.41	2.52
4	Peak power loss (MW)	1.34	0.28
5	Proposal made		HVDS and Improvements of HT lines
6	Proposal A: HVDS cost (Rs)		9,968,820
7	Proposal B: reconductoring of 11 kv squirrel to weasel km		5.2
8	Cost per unit length (Rs)		37,000
9	Proposal C: additional circuit		Additional circuit
10	Proposal km		10
11	Cost per unit length (Rs)		107,760
12	Total Investment for the proposal (A+B+C, Rs)	11,238,820	
13	Interest charges (%)		10.0
14	O and M charges (%)		3.0
15	Life of the project (years)		20
16	Energy charges per unit (Rs)		2.3
17	Annual expenses (Rs)		1,461,046.6
18	Energy savings (units/year)		1,776,803.2
19	Annual income on energy saving (Rs)		4,086,647.4
20	Annual benefit		2,625,600.8
21	Annuity factor		8.51
22	Present worth of annual benefit		22,353,219.4
23	Net present worth		11,114,399.4
24	Benefit to investment ratio		1.99
25	Feasibility of project		Feasible
26	Payback period (years)		10

In case 3 and case 4 of the feasibility study the payback period is more than 10 years, as in this case other benefits of energy savings due to HVDS are not considered.

- As per the 11 kv energy flow diagram of BESCOM for the year 2002/2003 the average total loss for the rural feeders is about **35%**, including commercial loss of **12.1%**. From the loss computation of the Budhigere feeder the energy loss is **28.1%** and the commercial loss is about **7%**. By implementing HVDS, the commercial losses will be minimized to less than **2%**. The **5%** energy loss reduction will be accounted for the loss reduction due to HVDS, that is, 746,820*0.05*12, which equals 4,48,092 units per year

In the existing scenario the total single-phase load on this feeder is about 195 kw (10.8 A), whereas the recorded current for this branch during single phasing is 180 A for two hours a day. It indicates that during single phasing some of the IP sets are running. This can be completely minimized by implementing HVDS. There will a consumption of 6,126 (6,516-195*2) units per day of IP sets even during single-phase operation. There will be energy savings of 2,235,981 units per year by this system. HVDS also has the flexibility of controlling the consumption of IP sets depending on the supply conditions. The feasibility reports were modified by considering the above facts and are presented in Table AppA-20

Table App 1-20: Feasibility Report for HVDS

Sl No	Description	HVDS	HVDS with Improvements
1	Peak load (A)	194	177
2	Sending end power at peak load (MW)	3.07	2.80
3	Total load at peak load (MW)	2.52	2.52
4	Peak power loss (MW)	0.55	0.28
5	Proposal made	HVDS	HVDS and improvements of HT lines
6	Proposal km		192,400
7	Cost per unit length (Rs)	9,968,820	9,968,820
8	Proposal made	Improvements	Additional circuit
9	Proposal km	-	10
10	Cost per unit length (Rs)	-	107,760
11	Investment in the proposal (Rs)	9,968,820	11,238,820
12	Interest charges (%)	10	10
13	O and M charges (%)	3	3
14	Life of the project (years)	20	20
15	Energy charges per unit (Rs)	2.3	2.3
16	Annual expenses (Rs)	1,295,946.6	1,461,046.6
17	Energy savings due to HVDS (units/year)		1,776,803
18	Energy savings commercial loss reduction (units/year)	448,092	448,092
19	Energy savings due to controlled three-phase supply for IP sets (units/year)	2,235,990	2,235,990

Sl No	Description	HVDS	HVDS with Improvements
20	Total energy savings (units/year)	3,947,636.8	4,460,885
21	Annual income on energy saving (Rs)	9,079,564.6	10,260,035.9
22	Annual benefit	7,783,618	8,798,989.4
23	Annuity Factor	8.51	8.51
24	Present worth of annual benefit	66,266,328.2	74,910,756.6
25	Net present worth	56,297,508.2	63,671,936.6
26	Benefit to investment ratio	6.7	6.7
27	Feasibility of project	Feasible	Feasible
28	Payback period (years)	2.9	2.9

1.5 Conclusions and Recommendations

Based on the simulation studies, the benefits of the HVDS are as follows:

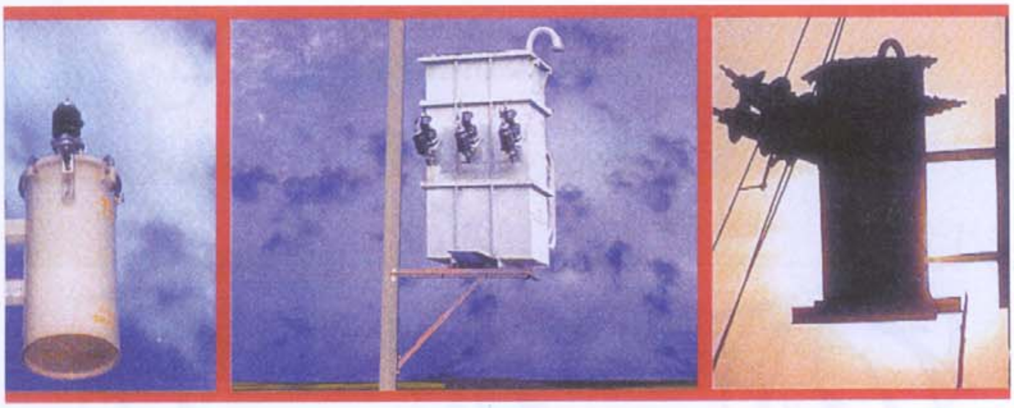
1. Reduction of total line real power loss from 1310 kw to 550 kw with HVDS alone and from 1310 kw to 280 kw with HVDS and improvements in HT lines in the distribution system;
2. Reduction of LT line losses (450 kw to 34 kW);
3. Improved voltage regulation;
4. The single-phase supply will be made available for all domestic and commercial consumers throughout the day;
5. Connection of single-phase transformers on all three phases gives better system performance. This also results in minimizing unbalanced current during three-phase operation (Alternative 2).

Further, based on the studies conducted, the following recommendations are made:

1. Peak load currents of individual IP sets should be measure before connecting the three-phase transformers;
2. All the single-phase transformers should be provided with proper grounding arrangements; and
3. The single-phase transformers should be connected to each phase based on the total single-phase connected loads.

Table App 1-21: Feasibility Analysis Summary

Sl No	Description	Base Case	Case 1	Case 2	Case 3	Case 4
1	Peak load (A)	230	215.3	202.5	194	177
2	Sending end power (MW)	3.75	3.49	3.22	3.02	2.85
3	Total load met (MW)	2.41	2.49	2.53	2.52	2.52
4	Peak power loss (MW)	1.34	1	0.69	0.55	0.28
5	Proposal made	-	Reconductor-ing of HT line	Reconductor-ing of HT and LT line	HVDS 30 single-phase and 196 three-phase transformers	HVDS with additional circuit of HT line
6	Proposal km		4.65	4.65		Reconductor-ing 192400.0
7	Cost per unit length (Rs)		107,760.0	107,760.0	9,968,820.0	9,968,820.0
8	Proposal made		Reconductor-ing	Reconductor-ing	Improvements	Additional circuit
9	Proposal km		10.0	20.0	-	10.0
10	Cost per unit length (Rs)		60,081.0	60,081.0	-	107,760
11	Investment in the proposal (Rs)		1,101,894.0	1,702,704.0	9,968,820	11,238,820
12	Interest charges (%)		10	10	10	10
13	O and M charges (%)		3	3	3	3
14	Life of the project (years)		20	20	20	20
15	Energy charges per unit (Rs)		2.3	2.3	2.30	2.30
16	Annual expenses (Rs)		143,246.2	221,351.5	1,295,946.6	1,461,046.6
17	Energy savings (units/year)		601,485.1	1,194,572.1	3,947,636.8	4,460,885.2
18	Annual income on energy saving (Rs)		1,383,415.7	2,747,515.9	9,079,564.6	10,260,035.9
19	Annual benefit		1,240,169.5	2,526,164.4	7,783,618.0	8,798,989.4
20	Annuity factor		8.51	8.51	8.51	8.51
21	Present worth of annual benefit		10,558,262.5	21,506,661.9	66,266,328.2	74,910,756.6
22	Net present worth		9,456,368.5	19,803,957.9	56,297,508.2	63,671,936.6
23	Benefit to investment ratio		9.58	12.63	6.7	6.7
24	Feasibility of project		Feasible	Feasible	Feasible	Feasible
25	Payback period (years)		2.2	1.6	2.9	2.9



Connector Installation

Universal Distribution Connectors are extremely easy to install.

Note: Large Wire

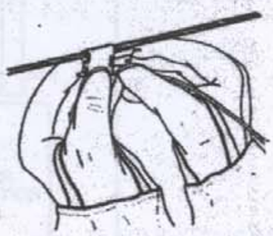
When connecting wires of different sizes, the larger wire must be placed in the large wire groove of the wedge.

1

Place the service entrance conductor in the lower groove of the "C" component.

2

Hook the "C" component along with the service entrance conductor over the main conductor while holding the assembly firmly by hand.

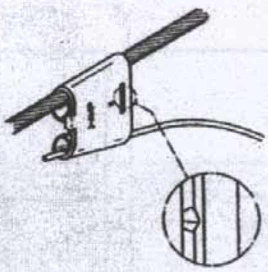


3

Adjust and gently push the "Wedge" component between the conductors with the fingers, making sure the clip is facing the correct direction (i.e., toward the window opening of the "C" component).

4

Complete the connection using parallel jaw pliers.



5

Be sure that installation is correct by checking to see that the clip on the "Wedge" component is protruding through the window opening on the "C" component.

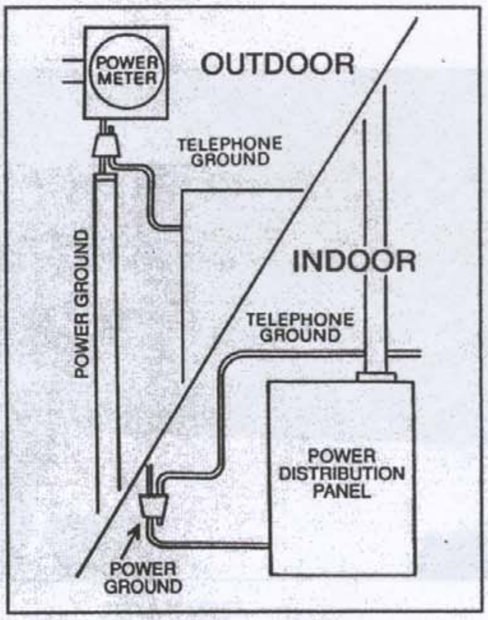
Typical Applications

Telephone grounding

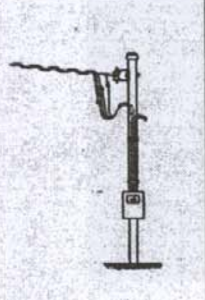
Street lights

Service entrance drops

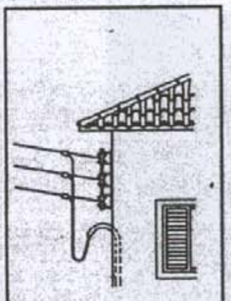
Aerial connections



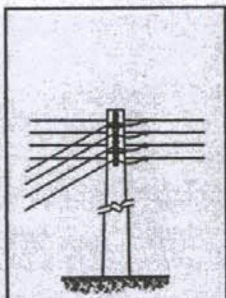
Residential/Commercial Grounding



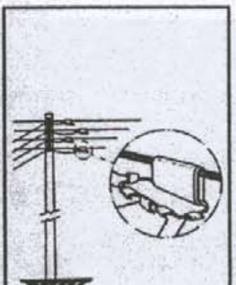
Consumer Entrance Service



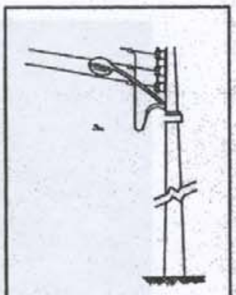
Consumer Entrance Service



Copper secondary service drop

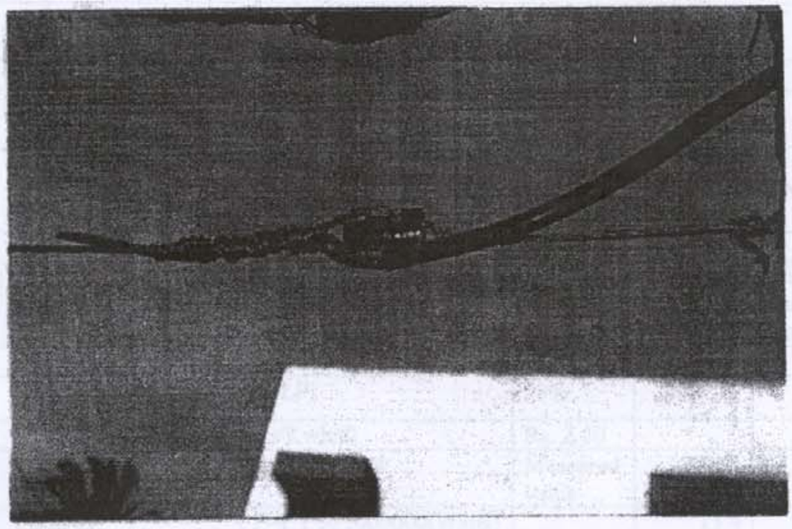


Aluminum secondary service drop using "AMPACT Stirrup" for low voltage

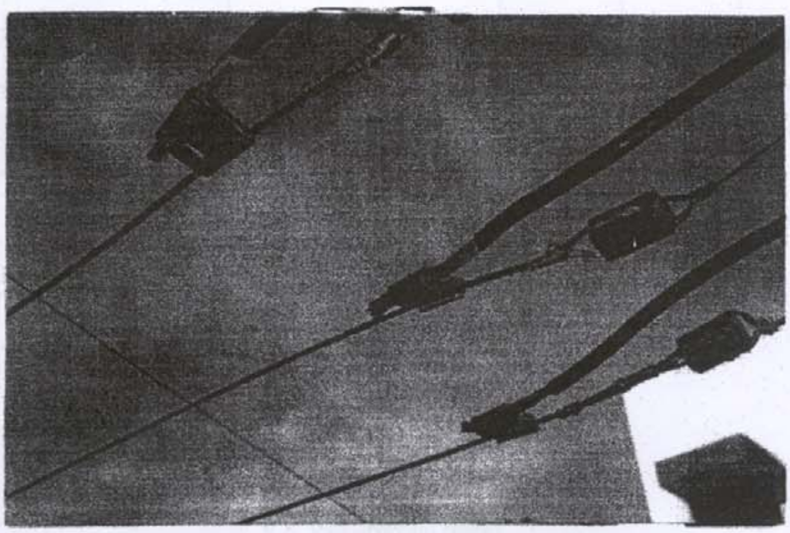


Street light connection

Connections near transformer center before and after fixing of new connectors



BEFORE



AFTER

ADVANTAGES OF FIRED WEDGE CONNECTORS IN LT APPLICATIONS

Field study details

APPLICATION	240 SQ.MM to RABBIT CONDUCTOR
PRESENT JOINT USED	WRAPPING JOINT
NEW APPLICATION TRIED OUT	FIRED WEDGE CONNECTOR
LOCATION	NEAR A TRANSFORMER IN BAN GALORE

Sl.no	Parameter	Formula	Value of unit	Wrapped joint data	Fired wedge joint
1	Rated current	Amps (I)	333.4		
2	Load factor	%(LF)	50%		
3	Cost of power	Rs/Kwhr©	Rs. 2.50		
4	Connector contact resistance	Micro ohms®	Measured value	554.3	70.0
5	Energy loss/connector in watts	P=I*I*R/1000000(Watts)		15.4	1.9
6	Energy loss/connector/year in kwhr	L=P*8760*LF		134.9	17.0
7	Annual loss /connector in Rs.	AL=L*C		337.3	42.6
8	Service life	N (years)	20		
9	Total monetary loss in connector in Rs.	TPL=AL*N		6747	852

If there are 25000 transformers carrying this much load then annual savings will be 25000*5895/20*3=Rs 22.1 million/year. Similarly there are millions of house/consumer connections where loss reduction is possible.

V.S .Rao –Nexant report

A CASE STUDY OF K.P.T.C.L AT VIDYANAGARA NEAR BAN GALORE WHERE AUTO RECLOSURE WAS INSTALLED:

Feeder is a semi- industrial feeder close to Ban galore.

Length of the feeder is 30 kms.

Load on the FEEDER---270-300 amps.

Load consists 28 stone crushers of 25-30 hp after which there are rural loads. There are 6 HT installations and large irrigation loads.10, 000 consumers.

Revenue is Rs.2 million per month.

Interruptions---15/month with 6 faults permanent

Time taken to attend the fault 2-3 hours

Auto reclosure provided after all the industries and just before the rural loads.

Cost of auto reclosure is Rs. 0.2 million and sectionaliser is Rs.0.15 million

Sub-station breaker tripping used to interrupt supply to all HT/power installations.

Direct revenue loss= 6faults/month*3hrs*12*2000kw(average industrial load)*3.0/unit (avg. tariff) = Rs.1.29 million.

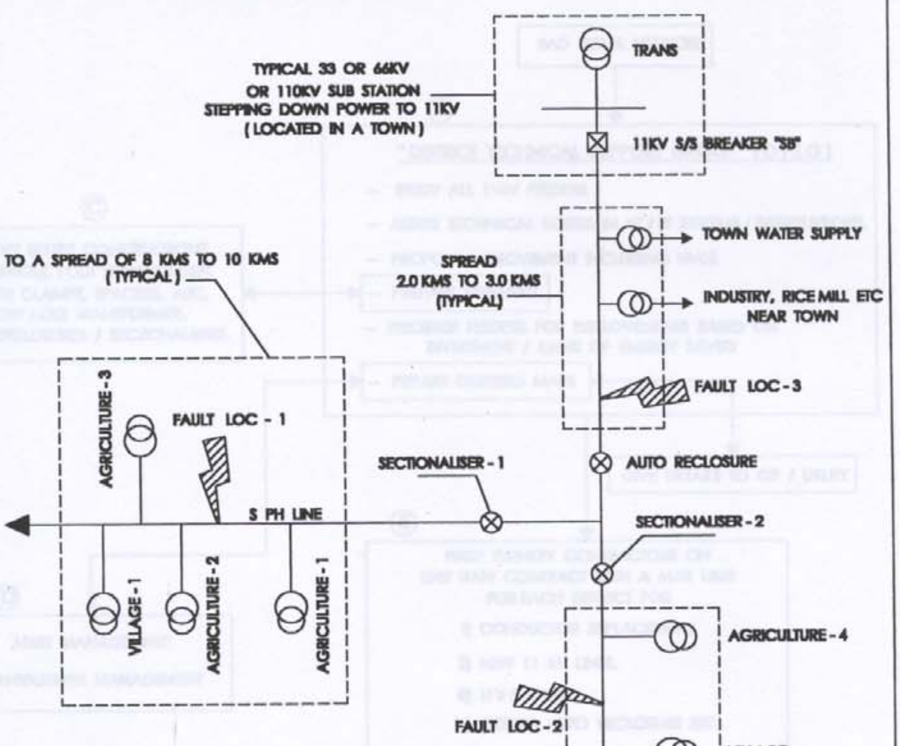
Fault repair cost not considered.

Investment Recovered in 0.35/1.29*12=3.69 months. ~4 months if maintenance costs are included.

There is greater justification for use of these units in rural areas as the faults are more and repair time is higher by a factor of at least 2.

V.S.Rao—Nexant Report

TYPICAL ARRANGEMENT OF USING AUTO RECLOSURES / SECTIONALISERS IN RURAL DISTRIBUTION.



CASE - A WITHOUT AUTO RECLOSURES / SECTIONALISERS :

I) FAULT AT LOCATION 1 OR 2. POWER SUPPLY IS AFFECTED TO ALL. RESTORATION TIME IS LONG

II) DUTY ON STATION BREAKER "SB" IS HIGH AS IT TRIPS FOR ALL FAULTS.

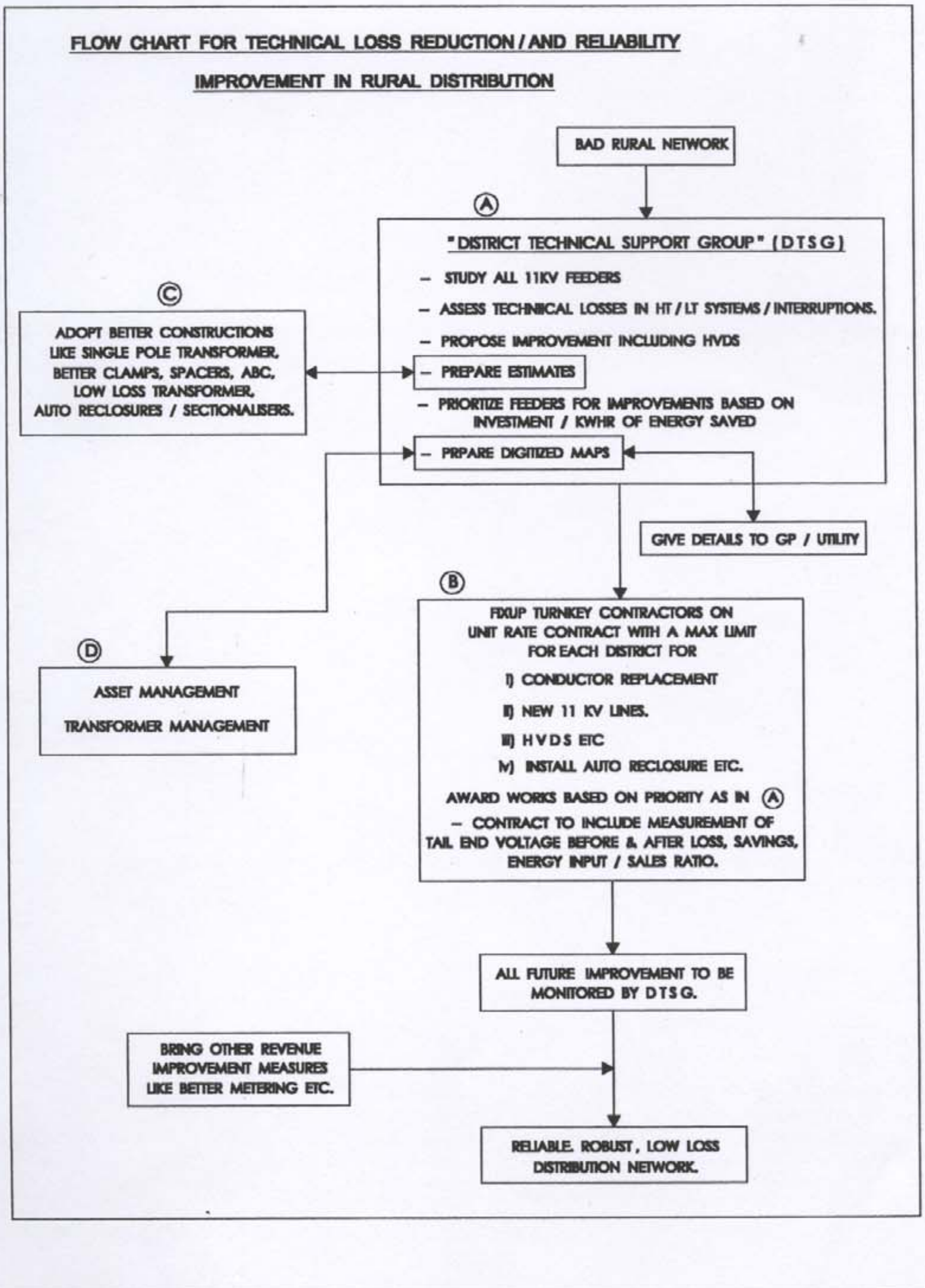
CASE - B WITH ONE AUTO RECLOSURES & TWO SECTIONALISERS :

I) FAULT AT LOCATION - 1 :
SECTIONALISER 1 ISOLATOR & SUPPLY CONTINUED TO OTHER AREAS INCLUDING TO WATER SUPPLY, LOCAL INDUSTRY. RESTORATION TIME IS LESS AS FAULT IS LOCALISED.

II) FAULT AT LOCATION - 2.
SAME AS I) ABOVE.

III) ONLY FAULT AT LOCATION - 3 :
AFFECTS ALL, BUT RARE. THIS PORTION OF LINE CAN ALSO BE WELL MAINTAINED TO REDUCE FAULTS. REVENUE INCREASES AS SUPPLY TO REVENUE YEILDING INSTALLATIONS IMPROVE.

IV) DUTY ON STATION BREAKER "SB" REDUCES AS AUTO RECLOSURE TAKES OVER THE FAULT TRIPPING FOR MAJORITY OF THE LINE FAULTS.


FLOW CHART FOR TECHNICAL LOSS REDUCTION / AND RELIABILITY
IMPROVEMENT IN RURAL DISTRIBUTION
BAD RURAL NETWORK
A
"DISTRICT TECHNICAL SUPPORT GROUP" (D T S G)
– STUDY ALL 11KV FEEDERS
– ASSESS TECHNICAL LOSSES IN HT / LT SYSTEMS / INTERRUPTIONS.
– PROPOSE IMPROVEMENT INCLUDING HVDS
– PREPARE ESTIMATES
– PRIORTIZE FEEDERS FOR IMPROVEMENTS BASED ON INVESTMENT / KWHR OF ENERGY SAVED
– PRPARE DIGITIZED MAPS
C
ADOPT BETTER CONSTRUCTIONS LIKE SINGLE POLE TRANSFORMER, BETTER CLAMPS, SPACERS, ABC, LOW LOSS TRANSFORMER, AUTO RECLOSURES / SECTIONALISERS.
GIVE DETAILS TO GP / UTILITY
B
FIXUP TURNKEY CONTRACTORS ON UNIT RATE CONTRACT WITH A MAX LIMIT FOR EACH DISTRICT FOR
I) CONDUCTOR REPLACEMENT
II) NEW 11 KV LINES.
III) H V D S ETC
IV) INSTALL AUTO RECLOSURE ETC.
AWARD WORKS BASED ON PRIORITY AS IN A
– CONTRACT TO INCLUDE MEASUREMENT OF TAIL END VOLTAGE BEFORE & AFTER LOSS, SAVINGS, ENERGY INPUT / SALES RATIO.
D
ASSET MANAGEMENT
TRANSFORMER MANAGEMENT
ALL FUTURE IMPROVEMENT TO BE MONITORED BY D T S G.
BRING OTHER REVENUE IMPROVEMENT MEASURES LIKE BETTER METERING ETC.
RELIABLE, ROBUST, LOW LOSS DISTRIBUTION NETWORK.